Optical Readout of MEMS

P. G. DATSKOS
University of Tennessee

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Introduction

Over the past decade the field of micro-electro-mechanical systems (MEMS) has attracted increased interest. Miniaturization of mechanical systems promise new directions in the progress of science and technology.

For a large number of sensing applications the determination of positional changes in microstructures becomes of interest (especially when applied to arrays).

Positional changes of less that 10 pm are routinely measured in atomic force microscopy (AFM). These techniques include: tunneling, optical deflection, interferometry (two color or diffractive), capacitive, piezoresistive, piezoelectric, magnetic.

However, one of the most sensitive optical techniques for measuring small positional changes is the interferometer

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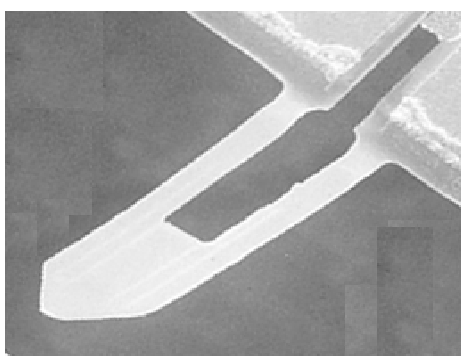
IR Detection Using Microstructres

- Thermal stress in semiconductors
  - Changes in the temperature of the device
- Photo-induced stress in semiconductors
  - Change in "free" charge carrier density
- The stress causes the microstructure detector to deflect. Therefore there is a need very sensitive deflection measurement techniques that can be applied to large arrays.

Piezoresistive Readout of Microstructures



Piezoresistive Pt-Si photon detector

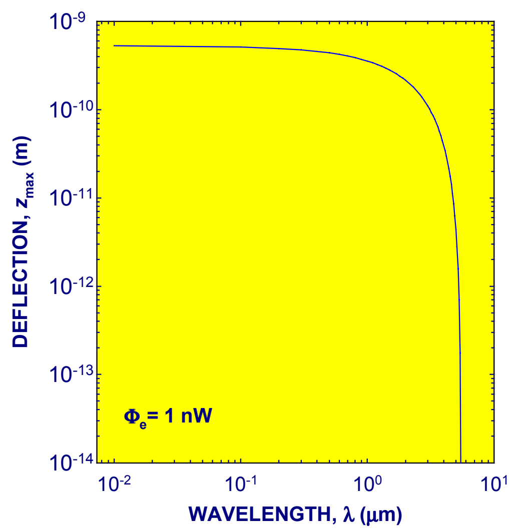
Micromechanical Bending due to Internal Photo-emission

$$z_{\max} \approx C_0 \frac{(1-\upsilon)\, l^2}{t} \frac{d\,\varepsilon_g}{d\,P} \frac{1}{l\;w\;t} \tau_L \left(1-\frac{\lambda}{\lambda_c}\right)^2 \Phi_e$$

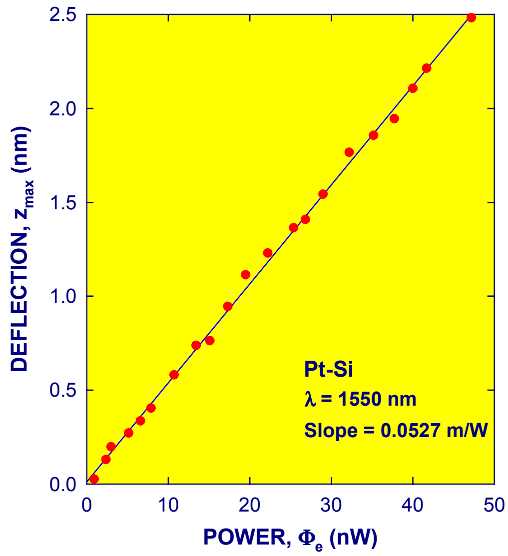
$$z_{\max} = C_0 \frac{l^2}{t_1+t_2} \left(\frac{1+(t_1/t_2)^2}{3(1+t_1/t_2)^2 + (1+t_1E_1/t_2E_2)\left(\frac{t_1^2}{t_2^2}+\frac{t_2E_2}{t_1E_1}\right)} \right) \frac{E_1}{E^*} \frac{d\,\varepsilon_g}{d\,P} \frac{\tau_L}{l\,w(t_1+t_2)} \left(1-\frac{\lambda}{\lambda_c}\right)^2 \Phi_e^{abs}$$

z_{max}	deflection of microcantilever tip
l; t; w	length; thickness; width
υ; E	Poison's ratio; Young's modulus
Φ_e	radiant power
C_0	quantum yield
τ_L	carrier lifetime

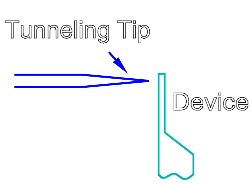
Calculated Micromechanical Deflection due to Photo-emission



Deflection Response



Tunneling Readout of Microstructures

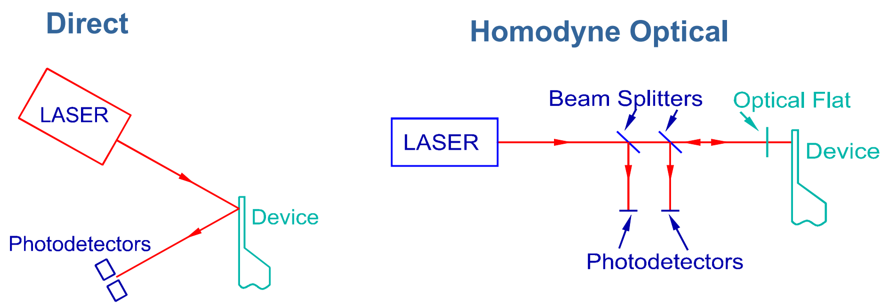


$$z = \frac{e^2}{} \frac{\kappa_0}{4\pi^2 z} V e^{-2\kappa_0 z}$$

Binnig and Rorher (1986)

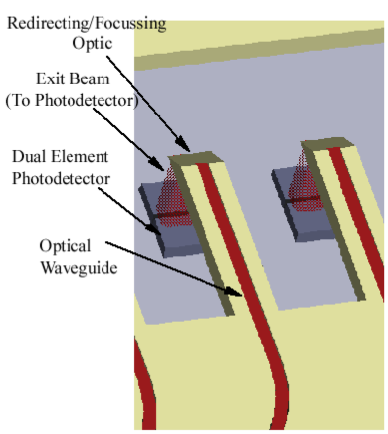
z : tunneling distance (in Angstroms)
V: bias voltage (in Volts)
k_0: inverse decay length of wavefunction

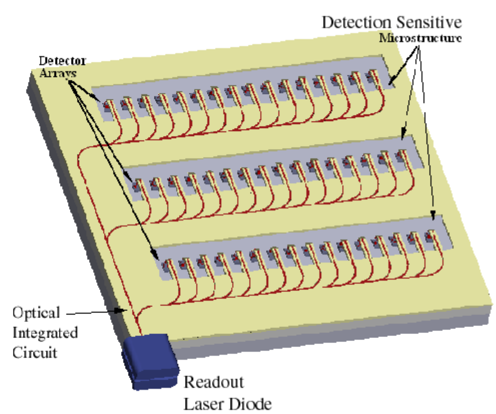
General Optical Readout Techniques for Position Detection



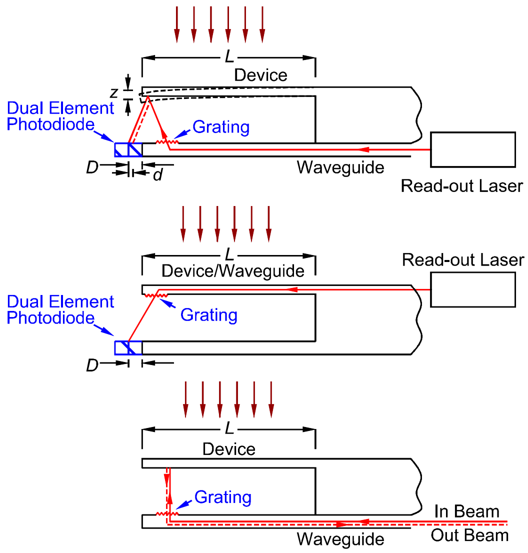
$$z_{noise}^{th} = \sqrt{\frac{2k_BTB}{\pi Qkf}} \approx 0.0005 \text{ nm}$$

Microposition Sensing Concept for Arrays



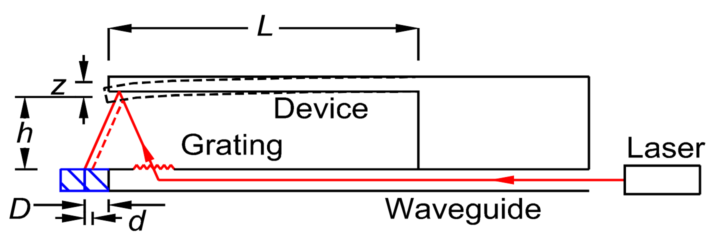


Miniaturized AFM, and Waveguide Interferometry



- Miniature AFM Concept
  - Easily implemented
  - Sub-nanometer resolution
  - Geometry independent
- Waveguide Interferometry
  - Compact design
  - Sub-nanometer resolution
  - Geometry independent
  - Multiple wavelengths color interferometry for increased sensitivity and dynamic range.

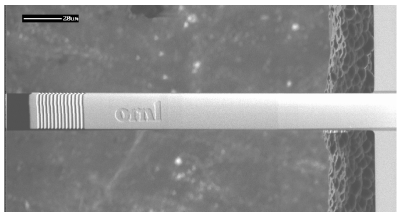
Resolution of Optical Deflection Readout Technique

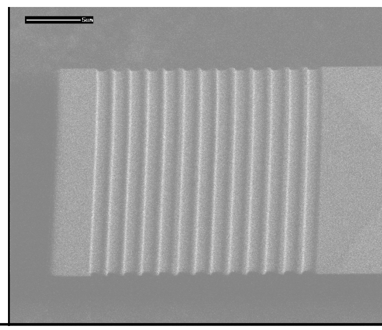


$$z = \frac{1}{2}\frac{\Delta i}{i}\frac{D}{h}L$$

L=150 µm, D=50 µm, h=150 µm $\Delta i/i = 10^{-6}$

Integrated Microdevice/Grating for Optical Coupling/Steering





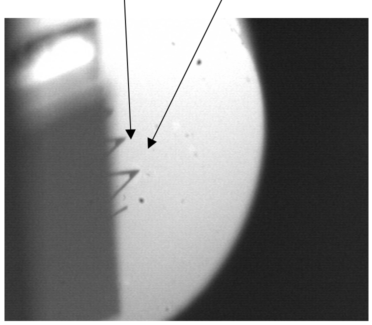
- SiNx microcantilever with an integrated grating that has a period of 1µm and a blaze angle of 45 degrees.
- Fabricated rapidly using direct write techniques.
- Grating can be used to couple or decouple laser light or provide collimation and focusing.

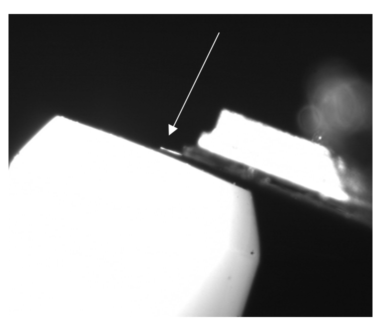
Optical Fiber Interferometer

Micro-Structure

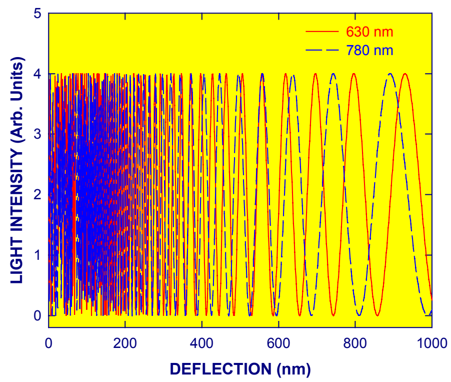
Single Mode Fiber core.

Micro-Structure

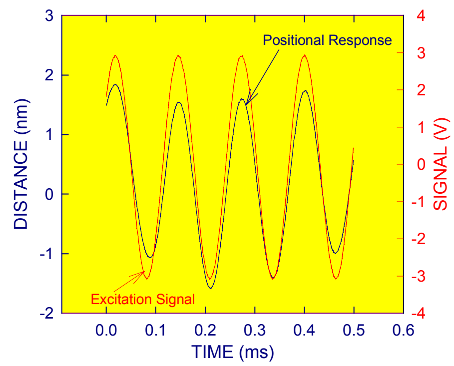




Microposition Determination Using Interferometry

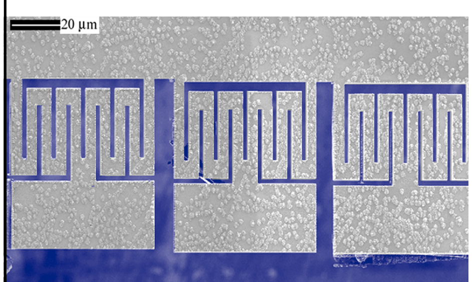


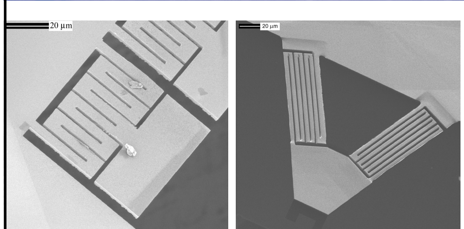
Two Color



One Color

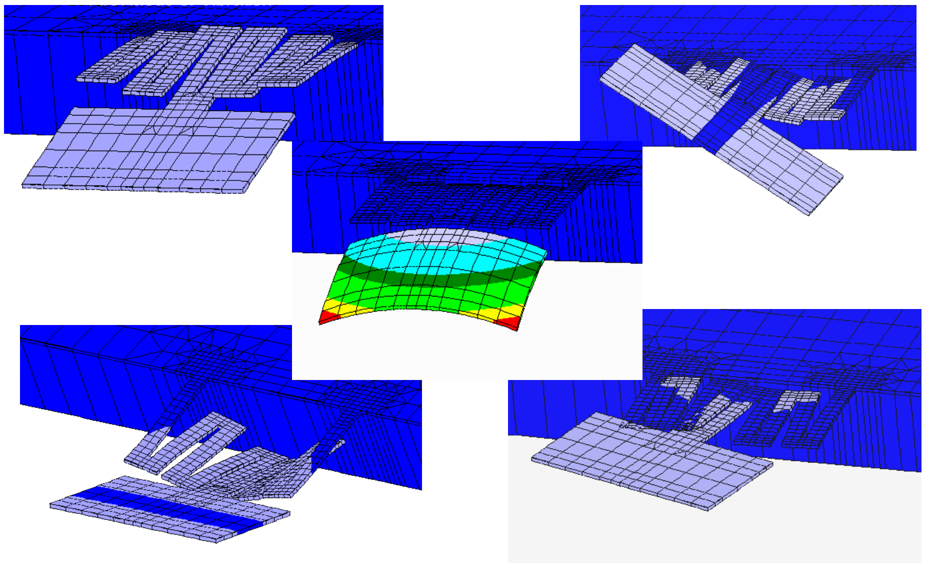
1999 R&D 100 Award Winning Micromechanical Photon Detectors





- ORNL fabricated small linear arrays of microstructures using rapid prototyping methods (made from InSb, GaAs, and Si/Pt).
- Such devices can be used as micromechanical (photon or thermal) detectors for infrared radiation.
- These devices have been produced using new microfabrication approaches.

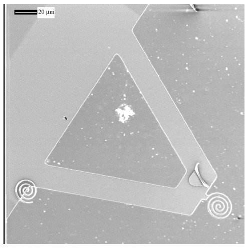
Micromechanical Device Modeling

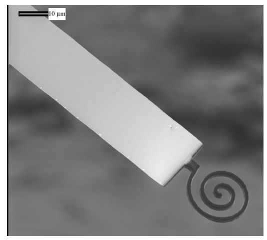


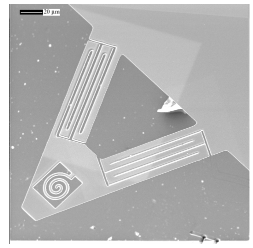
ORNL Micro-Fabrication Methods

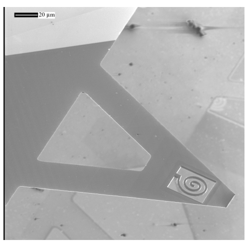
ORNL Focused Ion Milling System

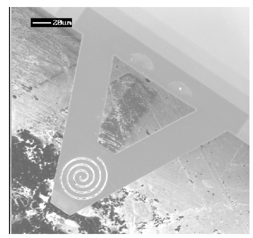
Optical Readout of Microstructures Based on Fresnel Zones



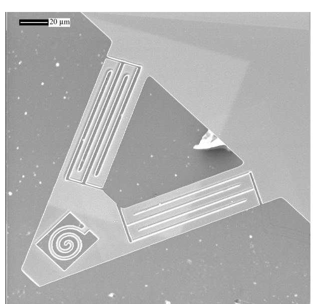


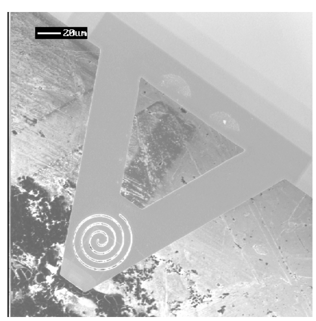


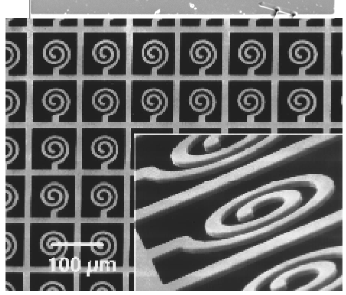


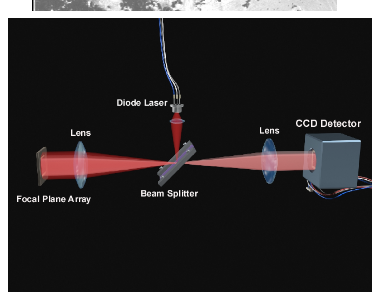


Diffractive Readout





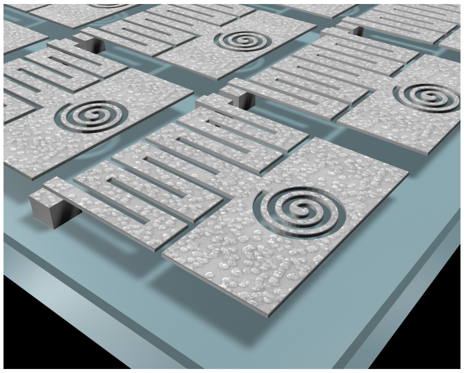




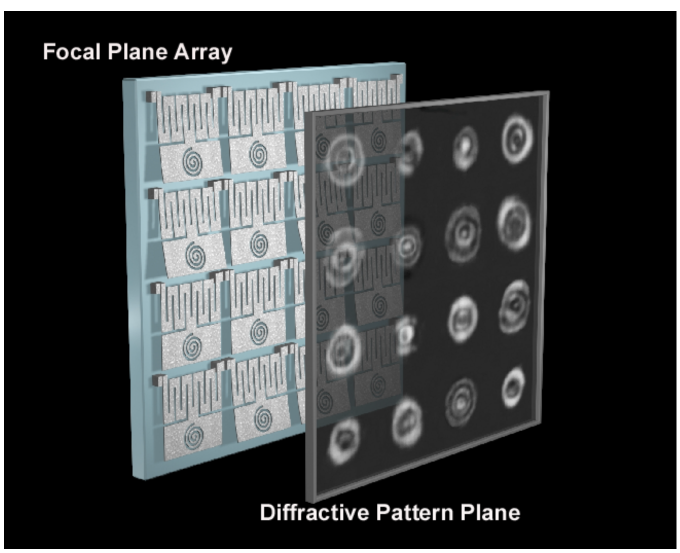
Manalis et al. Appl. Phys. Lett. (1997)

Datskos et al. (1999)

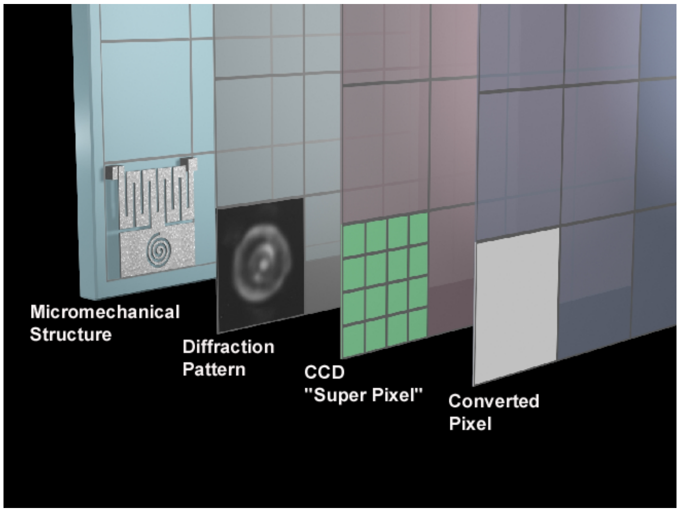
Diffractive Readout (cont.)



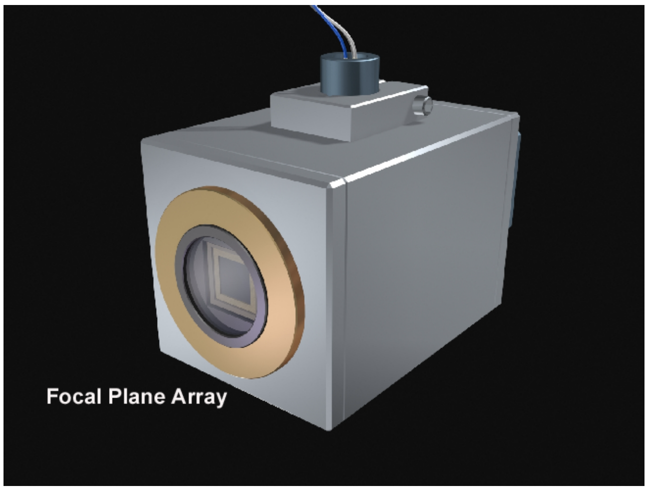
Diffractive Readout (cont.)



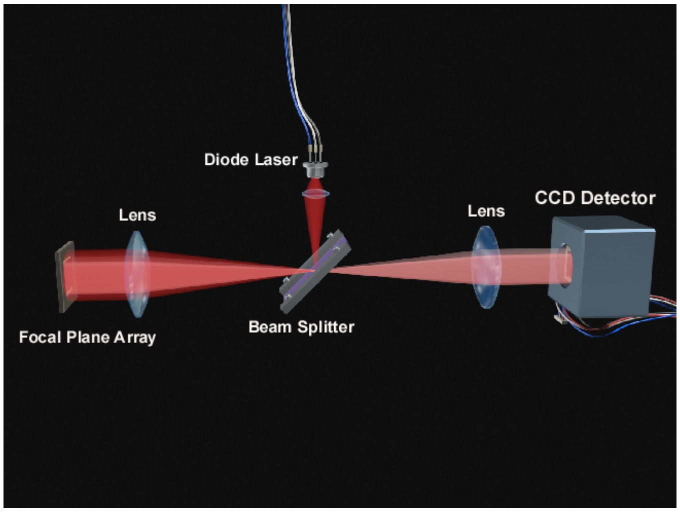
Diffractive Readout (cont.)



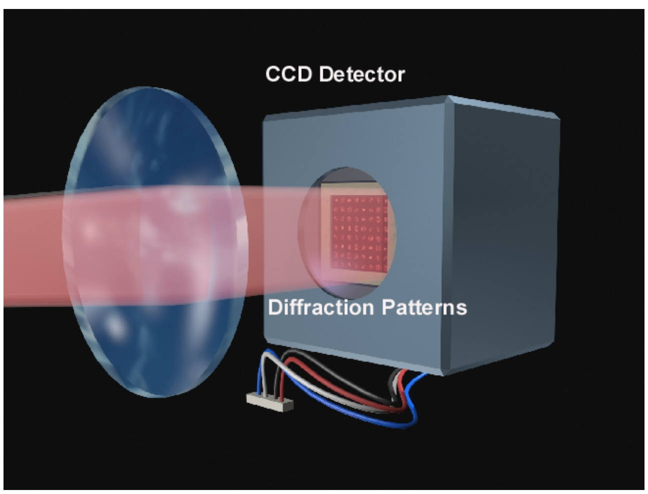
Camera Level Concept



Schematic of Diffractive Readout Technique



Diffractive Image Conversion



Conclusions/Summary

Techniques that are capable of measuring small positional changes in micromechanical structures can find applications in a number of IR sensing applications.

Positional changes of less that 10 pm are routinely measured in AFM with tunneling, optical deflection, interferometry, capacitive, and piezoresistive sensing techniques.

Optical based readout techniques such as interferometric (especially multicolor or diffractive) are among the most sensitive methods for measuring small positional changes. These become especially attractive when applied to readout of large arrays.